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Energy Absorption AZ31B using Quenching in Nano Fluid

(Penyerapan Tenaga AZ31B menggunakan Pemadaman Cecair Nano)

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ABSTRACT

This paper focuses on improving energy absorption through a series of heat treatment and quenching in medium, presence of nanoparticle. The characterisation of the experiment was to determine the suitable combination of composition factors: temperature, soaking time, and the medium that consist of nanoparticle on magnesium alloy surface structure to improve the energy absorption using quenching in nanofluids. The diameter and thickness of the specimen are 6 mm and 10 mm, respectively. All specimens undergo heat treatment based on the temperature of the furnace and the soaking time of the specimen in the furnace, which will be submerged into three medium distilled water, and the addition of a 0.1% wt carbon-nanotube (CNT) and 0.1% wt nano-silica. The addition of CNT and nano-silica shows an increment of 106.68%% and 59.30% for energy absorption, respectively, when compared to the controlled sample. Later microscopy has performed on the specimen to correlate the addition of nanoparticles in the heat treatment and improved energy absorption by EDS analysis on the material composition on the specimen's surface. Therefore, this paper reveals factors of heat treatment and the presence of CNT and Nano silica effects on enhancing magnesium alloy energy absorption: UTS and yield strength using quenching method.

Keywords: AZ31B; CNT; nano silica; quenching

ABSTRAK

Makalah ini memfokuskan pada peningkatan penyerapan tenaga melalui rangkaian rawatan haba dan pemadaman dalam medium nanopartikel. Pencirian eksperimen adalah untuk menentukan kombinasi faktor komposisi yang sesuai: suhu, masa rendaman, dan medium yang menggunakan nanopartikel pada struktur permukaan aloi magnesium untuk meningkatkan penyerapan tenaga menggunakan pemadaman dalam nanopartikel. Diameter dan ketebalan spesimen masing-masing adalah 6 mm dan 10 mm. Semua spesimen latihan rawatan haba adalah berdasarkan suhu tungku dan masa rendaman spesimen di dalam tungku, yang akan direndam menjadi tiga udara suling sederhana, dan penambahan 0.1% wt karbon-nanotube (CNT) dan 0.1% dengan nano-silika. Penambahan CNT dan nanosilika menunjukkan peningkatan 106.68 %% dan 59.30% untuk penyerapan tenaga berbanding dengan sampel terkawal. Mikroskopi kemudian dilakukan pada spesimen untuk mengaitkan penambahan nanopartikel dalam rawatan haba dan peningkatan penyerapan tenaga dengan analisis EDS pada komposisi bahan di permukaan spesimen. Oleh itu, makalah ini mendedahkan faktor perlakuan panas dan kesan CNT dan nanosilika pada peningkatan penyerapan tenaga aloi magnesium: UTS dan kekuatan hasil menggunakan kaedah pemadaman.

Keywords: AZ31B; CNT; nano silika; pemadaman

INTRODUCTION

Magnesium-based alloys are the current trend in the military industry because they are one of the lightest of all structural metal alloys (Abdullah et al. 2018; Balaji, S. et al. 2020) The density of magnesium is approximately 35% lower than that of aluminium and approximately 77% lower than that of steel (Balaji et al. 2020). Magnesium alloy is the lightest metallic material with a high potential for weight reduction, thereby decreasing the amount of fuel required in automobile and aerospace applications. However, compared to several conventional materials, such as steel, fewer studies have been performed on the relationship between magnesium alloys and impact loading (Yu et al. 2017), particularly under high-velocity impact conditions.

Magnesium has a hexagonal close-packed (HCP) structure. In HCP inorganic compounds, larger atoms (or ions) occupy positions corresponding approximately to equal spheres in close packing. In comparison, smaller atoms are distributed among the voids (Ceschini et al. 2017). For example, a material that can fill these voids is necessary to prevent structure collapse, such as carbon nanotubes (CNTs) with a nano-material structure. CNTs have unique properties that can produce solid materials and improve the energy absorption of other materials (Abdullah et al. 2018, 2016; Qian et al. 2018). The term toughness and energy absorption. The molecular nanotechnology of CNTs can fill the spaces in a structure and produce van der Waals bonds therein (Guo et al. 2019; Kresnodrianto et al. 2018). The fill-up nanoparticles on to material currently used is the quenching method where the surface roughness quenched faster, and it depends on particle size. (Gronostajski et al. 2018; Subramani et al. 2019) studied the effect of nanoparticle deposition on the minimum heat flux and quenched front speed during quenching in water-based nanofluids. Inspired by the idea of using nanofluids as quenchants, (Babu, Arularasan & Srinath Ramkumar 2017; Kresnodrianto et al. 2018) first used the CNT nanofluids as quenchants and found that the method of preparation played a vital role in determining the heat transfer rates during quenching.

The quenching method will improve the properties of magnesium alloy (Soltani, Shamanian & Niroumand 2017). Thus, magnesium is an excellent choice for high-velocity impact applications because of its enhanced energy absorption and shock mitigation. This alloy is suitable for armour plating to reduce armour weight whilst increasing the fuel consumption efficiency of armoured vehicles and providing high-velocity resistance. Rolled homogeneous armour (RHA) is steel-based and is currently used on armour plating. Improving RHA with magnesium alloy offers a new alternative that solves armour weight and fuel consumption problems whilst providing the same penetration resistance. According to the literature read by the authors of this paper, it is known that AZ31B is a material that can potentially replace RHA for armoured vehicles because of its impact behaviour. However, the composition of AZ31B has less strength to support the impact deformation structure (Salvado et al. 2017).

A combination of CNT and Nano silica on magnesium alloy may exhibit a high reduction of impact resistance. Therefore, CNT and Nano silica could be added to AZ31B to obtain increased ballistic resistance. This study aims to observe the behaviour of magnesium alloy reinforcement with CNT and Nano silica under high-velocity impact. The results will be given the correlation of energy absorption between mixture nanoparticle on the magnesium alloy.

Magnesium alloys are a new trend and interest in the industry, especially in military industry (Balaji, S. et al. 2020). Magnesium alloys are the lightest of all structural metal alloys, and even the density of the magnesium is also lower compared with other materials such as aluminium and steel.

However, this material has a disadvantage in ductility. Therefore, it can be changed if this material has a mixture of nano-materials in its structure. This research will investigate how magnesium alloy reacts with the mixture of nano-material by using Quenching Method.

Therefore, this study is about the effectiveness of the quenching method on magnesium alloy and how this material can improve the energy absorption by this method which is analysed by looking at the factor that can influence its performance in term of the percentage of Carbon Nano Tubes (CNT), percentage of nano silica, times and temperature. So, this method can be used in the military industry specifically for vehicles to maintain the ductility of the material in the vehicles.

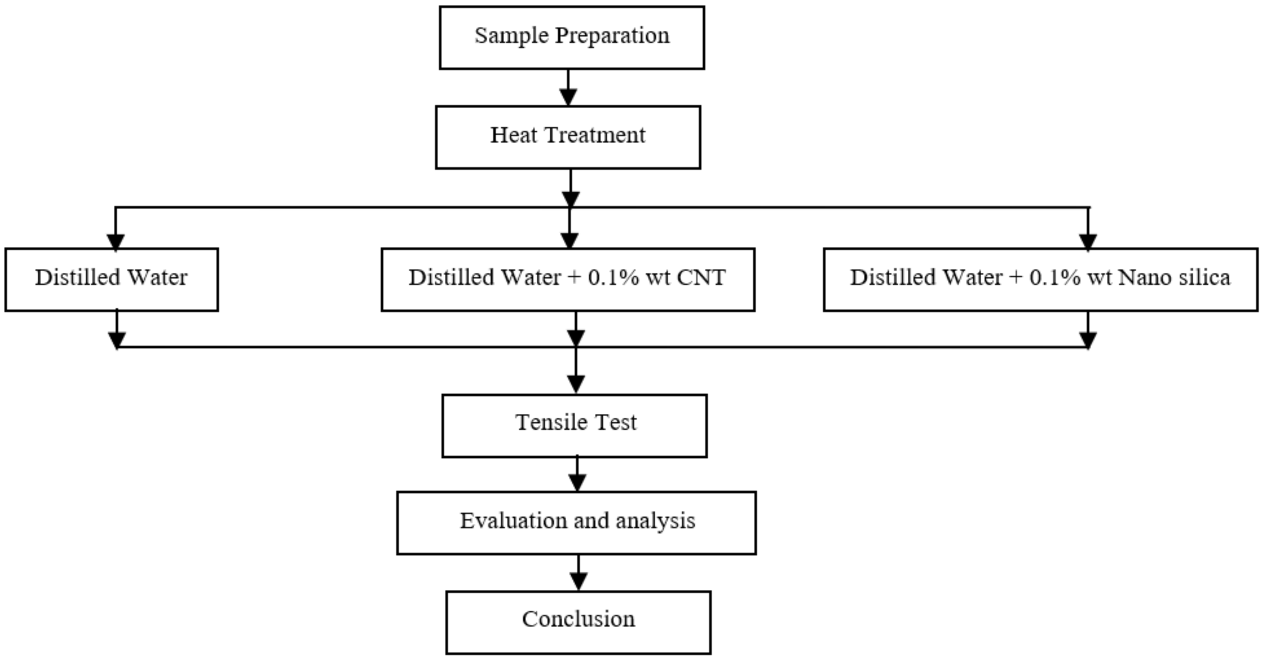


FIGURE 1. Flow diagram of the methodology

METHODOLOGY

The frameworks of the methodology in this study are constructed in Figure 1. Characterisation of each process and factors were illustrated. Heat treatment upon the selected magnesium alloy specimen, AZ31B, will undergo two factors that will contribute to the time soaking of specimen in the furnace and the temperature of the furnace based on the factorial designed. Combining CNT or nano-silica into distilled water to obtain a nanofluid medium for the specimen to be submerged, known as the quenching process, enhances specimen properties. A tensile test was carried out to determine the UTS and energy absorption, which later will compare with the teat treatment and quenching in nanofluids. The factorial model designed evaluated each main contributing factor that will increase the material properties focusing on energy absorption (Abdullah et al. 2018; Gronostajski et al. 2018).

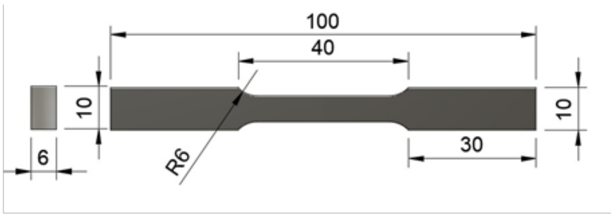


FIGURE 2. Geometrical properties of the specimen used for the tensile test
Source: Vander Voort & Baldwin (2004)

Theoretically, metal alloys that undergo heat treatment will achieve a higher tensile strength, but to some extent, will reduce their elongation due to achieving many brittle properties (Vander Voort & Baldwin 2004). Relating to energy absorption, the amount of area under the stress-strain curve gives the value (Salvado et al. 2017). Thus, the factors listed in contributing to energy absorption for the experiment are tensile strength, yield strength, and elongation.

The material used for the experiments was magnesium alloy AZ31B. Figure 2 presents the dog-bone shaped specimen for the tensile test, which was prepared based on the ASTM E8. The cross-section and the length of the gauge area were 6 mm x 6 mm and 25 mm, respectively. Specimen AZ31B before treated performed the tensile test and scored 220 Mpa, which is relevant compared to the standard AZ31B ASTM.

EXPERIMENTAL PROCEDURE

As CNT and nano silica were known to be hydrophobic (Guo et al. 2019; Qian et al. 2018), it is difficult to disperse them directly. Due to the sheer size of the nanocomposites, a certain amount of energy is required to breach the inter molecules forces between each particle. This would cause the nanocomposite to agglomerate even though it was mixed in distilled water. As a result, the nanofluid is not evenly dispersed uniformly throughout the medium, which would affect the results. The nanofluid preparation undergoes a specific procedure to ensure that the nano composition in the medium is dispersed uniformly (Babu et al. 2017).

All specimens were classified into 12 specimens evaluated in two manipulated process factors from the heat treatment factor and three medium that involves distilled water and nanocomposite to obtain nanofluids for the quenching process. Table 2 portrays the categorisations of each specimen.

As mentioned in Figure 1 and Table 2, the heat treatment process increases the magnesium alloy materials properties (Soltani et al. 2017). It focused on the two factors to analyse the most suitable heat treatment process that enhances the specimen, especially in terms of energy absorption. Later, the treated specimen will be submerged in a nanofluid water-based solution to apply the specimen's quenching process.

TABLE 1. Characterisation of specimen

No. of Specimen	Temp (oC)	Soaking time (min)	Medium Fluid Composition in 500 ml
1	260	30	Distilled water
2	260	60	Distilled water
3	350	30	Distilled water
4	350	60	Distilled water
5	260	30	Distilled water + 0.1% wt CNT
6	260	60	Distilled water + 0.1% wt CNT
7	350	30	Distilled water + 0.1% wt CNT
8	350	60	Distilled water + 0.1% wt CNT
9	260	30	Distilled water + 0.1% wt Nano Silica
10	260	60	Distilled water + 0.1% wt Nano Silica
11	350	30	Distilled water + 0.1% wt Nano Silica
12	350	60	Distilled water + 0.1% wt Nano Silica

TABLE 2. Chemical composition of Mg AZ31B alloy

Al	*Zn*	*Mn*	*Fe*	*Cu*	*Si*	*Ni*	*Mg*
3.28	1.00	0.44	0.0029	0.000039	0.025	0.00023	Balance

Source: Vander Voort & Baldwin (2004)

The quenching medium is prepared with 500 ml of distilled water + CNT/Nano Silica. These nanofluids were sonicated at 20 kHz for 15 minutes to get even dispersion of CNT/Alumina in distilled water by using a probe type ultrasonic processor QSonica 700 Sonicator.

Quench probes of magnesium alloy were used in this study to study the effect of quenching in CNT/Nano Silica nanofluids. The chemical composition of the magnesium alloy were measured at the first stage. The quench probes were heated up to near semisolid of magnesium alloy temperature. After a soaking time of several minutes, it will quench in three different mediums, as mentioned in Table 1. Figure 3 displays the sample preparation of the nanofluid as a medium to quench the magnesium alloy specimen, AZ31B, after the heat-treatment process.

EXPERIMENT ANALYSIS

A machine called Instron was used to perform the tensile test on the specimen and analyses the correlation of the energy absorption, which is known as tensile energy absorption (Abdullah et al. 2018). Measurement was taken upon the capacity of the material to withstand a shock when subjected to sudden high tension. The tensile force applied to a material is graphed against the percentage elongation of the specimen due to that force. The strain rate was fixed at 2 mm per minute for all specimen.

FIGURE 3. Sonicator set up to prepared nano medium

FIGURE 4. Tensile test setup

The mathematical determination of the area beneath the resulting curve is described as its tensile energy absorption. Trapezoid rule is a numerical integration method, a method to calculate approximately the value of the definite integral. Under this rule, the area under a curve is evaluated by dividing the total area into little trapezoids rather than rectangles. Let f(x) be continuous on (a,b). We partition the interval (a,b) into n equal subintervals as in the following equations:

$$\int_a^b f(x)dx \approx T_n = \frac{\Delta x}{2}[f(x_0)+2f(x_1)+2f(x_2)+...+2f(x_{n-1})+f(x_n)] \quad (1)$$

$$\Delta x = \frac{b-a}{n} \quad (2)$$

$$x_i = a + i\Delta x. \quad (3)$$

As n → ∞, the right-hand side of the expression approaches the definite integral ∫f(x)dx. From obtaining the area under the line from stress-strain data, abstract the amount of energy absorbed by the specimen(Abdullah et al. 2018).

SAMPLE PREPARATION FOR EDS ANALYSIS

To analyse the presence of nanoparticle on the surface of the specimen, all specimen was coated with a layer of gold to be observed under GeminiSEM 500. Energy Dispersive X-Ray Spectroscopy (EDS or EDX) is a chemical microanalysis technique used in conjunction with scanning electron microscopy. The EDS analysis was used to scan the presence of nano particle of all the specimen quenched in the nano medium (Veleva, Fernández-Olaya & Feliu 2018).

EDS functions with three major parts: an emitter, a collector, and an analyser. These parts are additionally typically equipped on an electron microscope such as SEM or TEM. The combination of these three pieces enables analysis of both how many X-rays are released and what their energy is (in comparison to the energy of the initial X-rays that were emitted). The figure below displays the setup of GeminiSEM 500 at UPNM.

FIGURE 5. FESEM setup

RESULTS AND DISCUSSION

TENSILE TEST ANALYSIS

Both the heat treatment process and preparation of nanofluid for the quenching medium affect the AZ31B specimen. The results of the tensile test of all specimen are portrayed in Table 3 and Figure 7. As obtaining the tensile test results for each specimen, the energy absorption is calculated from the area under the curve from the stress-strain until the specimen fails in Figure 6. Variety of amount of elongation and stress of each specimen affected due to the heat treatment and exposure to nanofluid during quenching process till specimen fails were analysed.

Thus, the energy absorption of each specimen is affected by the Ultimate Tensile Strength (UTS), the gradient of young Modulus and the percentage of elongation of specimen. Specimen 1 till 4 were treated in distilled water, specimen 5 till 8 in 0.1% wt of CNT and specimen 9 till 12 in 0.1% wt nano silica. Referring to Figure 8, the specimens that scored above 250 MPa for UTS were only the specimen treated in the 0.1% CNT solution, and the heat treatment of specimen at 350 oC for 1 hour all passed the eight value of strain. As we analysed the following tables related to the specimen results, the potential approach of enhancing magnesium alloy with nanofluid becomes plausible.

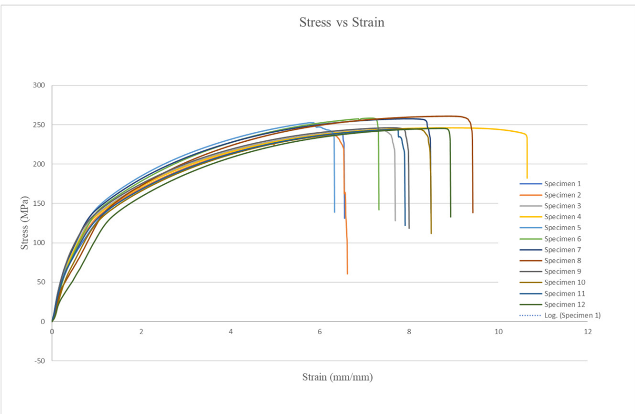


FIGURE 6. Stress-strain for all 12 samples

ENERGY ABSORPTION ANALYSIS

According to Table 3 on UTS, specimen 8 scores the highest percentage differences at 18.86% with the heat treatment factor of soaking time 60 min and heat temperature of 350°C when compared to the controlled sample. Regarding specimens 4 and 12 with the same heat treatment factor, they only scored 11.93% and 11.59%. Thus, 0.1% wt CNT contributes to the magnesium alloy specimen enhancement in Ultimate Tensile Strength. Theoretically, the CNT solution excels in enhancing the specimen Ultimate Tensile Strength.

Table 3 on yield strength indicates that specimen 8 also scores the highest percentage differences at 66.46% for yield strength. Regarding specimens 4 and 12 with the same heat treatment factor, they only scored 57.03% and 56.54%. Thus, 0.1% wt CNT contributes to the magnesium alloy specimen enhancement in Ultimate Tensile Strength. Theoretically, the CNT solution excels in enhancing the specimen Ultimate Tensile Strength.

The repetitive sequences of results can also be seen in the energy absorption in Table 3, where specimen 8 percentage differences from the controlled specimen are 106.68%. The response of the addition of CNT does not just give the highest in terms of similar heat treatment but from specimen 5, 6 & 7 scored outstandingly higher than the rest of the specimens which have been quenched in distilled water and nano silica. But still, specimen 4 and 12 percentage differences for energy absorption of 92.47% and 59.39%, respectively, are the highest if viewed from the similar quenching solution for each specimen. Thus, in terms of heat treatment, findings confirmed that magnesium alloy is best treated at 350°C for an hour.

TABLE 3. Characterisation of specimen results

Specimen	UTS (MPa)	Percentage of differences	Yield strength (MPa)	Percentage of differences	Energy absorption (J)	Percentage of differences
Control sample	220	-	138	-	38	-
1	239.08	8.67%	210.390	52.46%	42.7	12.37%
2	236.95	7.70%	208.518	51.10%	43.14	13.53%
3	243.87	10.85%	215.270	55.99%	53.45	40.66%
4	246.25	11.93%	216.704	57.03%	73.14	92.47%
5	252.77	14.90%	222.435	61.18%	53.41	40.55%
6	258.55	17.52%	227.527	64.87%	59.07	55.45%
7	257.78	17.17%	226.850	64.38%	57.33	50.87%
8	261.05	18.86%	229.726	66.47%	78.54	106.68%
9	246.32	11.96%	216.769	57.08%	53.83	41.66%
10	245.17	11.44%	215.747	56.34%	58.34	53.52%
11	243.95	10.89%	214.674	55.56%	56.21	47.92%
12	245.49	11.59%	216.029	56.54%	60.57	59.39%

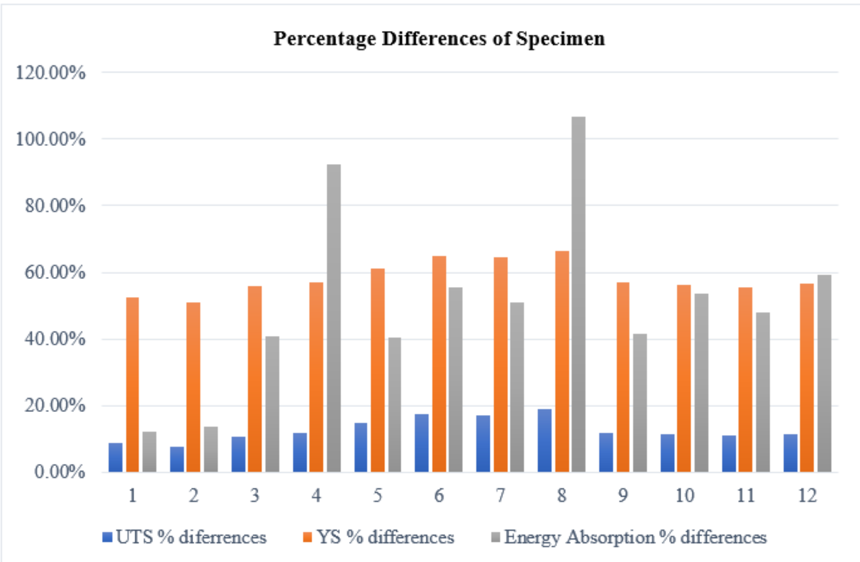


FIGURE 7. Percentage difference of specimen

From Figure 7, the pattern of trends fluctuates as observed by the increased number of specimens. As each specimen is treated under different conditions and methods, generally, the samples can be categorised according by quenching medium: distilled water, addition of 0.1% wt CNT, and 0.1% nano silica. This category then analyses similar trends of increment for ultimate tensile strength (UTS), yield strength (YS), and energy absorption.

For specimens 1 till 4 which was quenched in distilled water displayed increment trends for all three variables. Meanwhile, specimens 5 till 8 and 9 till 12 were quenched in treated distilled water sonicated with 0.1% wt CNT and 0.1% wt nano silica, respectively, displays fluctuated trend. Compared with specimen quenched in distilled water and nano silica where it doesn't portray an excellent medium to improve the materials property, especially in terms of toughness. All the specimens that were quenched in CNT medium depict the more suitable medium compared to the rest.

The increasing trend, especially on energy absorption of magnesium alloy according to each quenching medium on the heat treatment factors. The AZ31B best specimen were 8, 4, and 12, which all undergo heat treatment of 350°C with a soaking time of one hour. The addition of CNT in Later EDS analysis will focus on these three specimens.

EDS ANALYSIS

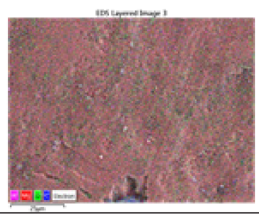
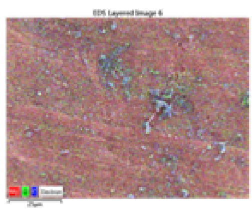
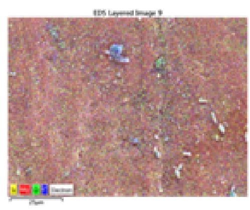
Energy Dispersive X-Ray Spectroscopy (EDS) in one of a few instruments in an electron microscope such as SEM or TEM to identify material composition on the surface of a specimen.

Table 4 shows the EDS analysis of the material composition of the specimen surface. Meanwhile, Table 5 displays the selected three best specimen mapping of EDS imagery. The material composition also can be observed in Figure 8, which displays a bar chart related to the percentage material distribution on the specimen's surface.

TABLE 4. EDS analysis of material composition

	Element Wt%											
Specimen	1	2	3	4	5	6	7	8	9	10	11	12
Mg	67.12	62.76	65.35	61.51	69.05	57.85	59.44	55.43	61.48	60.89	64.78	63.25
C	17.97	21.67	19.02	21.88	23.55	32.91	29.84	33.72	21.12	20.66	19.91	18.27
O	11.76	12.83	13.21	14.65	5.67	9.24	10.73	10.85	9.99	9.18	8.18	8.14
Si	-	-	-	-	-	-	-	-	7.41	9.27	7.13	10.34
Al	3.15	2.74	2.42	1.96	1.72	-	-	-	-	-	-	-

TABLE 5. EDS imagery of 3 selected specimen

EDS imagery		
		
Specimen 4	Specimen 8	Specimen 12

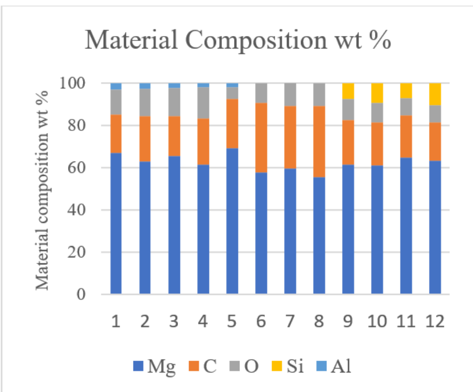


FIGURE 8. Material composition wt %

In relating to the energy absorption analysis and the EDS analysis of the specimen, a similar fluctuating trend of material composition on the surface of the specimen. The numbers of the material composition proved the presence of nanoparticle on the surface of the specimen.

By observing Table 5 related to EDS imagery of specimen 8, it displays a clear presence of concentrated area in carbon elements in blue, like EDS imagery for specimen 12 which displays presence of silica in yellow.

The first four specimens were quenched in distilled water shows the decrease pattern of aluminium. All the specimen that undergo quenching in nano silica medium show signs of the existence of silica elements. The quenching process doesn't coat the specimens with a layer of substance but rather treating the outer surface to harden as temperature fall dramatically (Babu et al. 2017). Thus, nanoparticle exposure on the surface of specimens impacts the energy absorption of AZ31B magnesium alloy.

CONCLUSION

This paper facilitates selecting appropriate factor values for 350°C and around 60 minutes for the soaking time for future application on enhancing AZ31B material properties as all the trends show the best heat treatment value compared to the other. Although the specimens were quenched in distilled water, CNT, and nano silica solution, the three specimens treated in each solution were the specimens under the factor variable mentioned earlier in terms of energy absorption were 92.47%, 106.68%, and 59.39%, respectively. The quenching solution clearly shows that CNT scored 78.54 J, with an increment of 106.68% from the controlled specimen. The EDS analysis proves the presence of nanoparticle on the specimen's surface and displays a similar trend related to the material composition and energy absorption analysis.

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DECLARATION OF COMPETING INTEREST

None

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